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Phytoliths and phytolith carbon occlusion in aboveground vegetation of sandy grasslands in eastern Inner Mongolia, China

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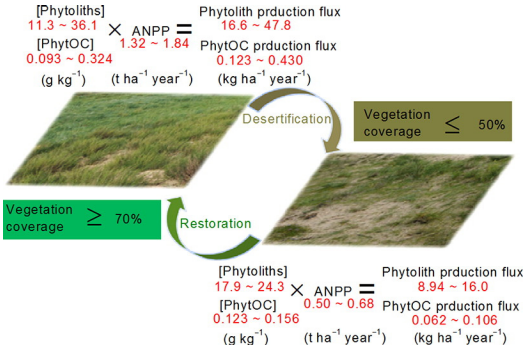
HIGHLIGHTS

- Grasslands play a crucial role in the long-term carbon sequestration of phytoliths.
- Desertification has occurred extensively in sandy grasslands of northern China.
- Phytolith production flux in sandy grasslands was 8.94–47.8 kg ha^{-1} year^{-1}.
- PhytOC production flux in sandy grasslands was 0.06–0.48 kg ha^{-1} year^{-1}.
- Desertification significantly decreases the phytolith and PhytOC production fluxes.

GRAPHICAL ABSTRACT



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ABSTRACT

Grasslands play a crucial role in the coupled biogeochemical cycles of carbon (C) and silicon (Si) because they have a large biogenic Si pool (i.e. phytoliths). In recent decades, desertification has occurred extensively in sandy grasslands due to human activities and to increased aridity as a consequence of climate change. The present study determined the contents of phytoliths and C occlusion within phytoliths (PhytOC) in sandy grassland with different vegetation coverage from eastern Inner Mongolia, China and preliminarily assessed the effects of desertification on phytoliths and PhytOC production. Our results showed that the phytolith and PhytOC contents among different plant species varied from 0.68 to 9.23% and 0.03 to 1.13‰, respectively. However, the community-weighted means of the phytolith and PhytOC contents for the total aboveground vegetation were only 1.13–3.61% and 0.09–0.35‰, respectively, and their respective production fluxes ranged from 8.94 to 47.8 kg ha^{-1} year^{-1} and from 0.06 to 0.48 kg ha^{-1} year^{-1}, respectively. As desertification progressed, the total contents of phytoliths and PhytOC in aboveground vegetation did not change significantly, whereas the production fluxes of phytoliths and PhytOC were markedly reduced. This study indicates that grassland desertification decreases the range of the total contents of phytolith and PhytOC by reducing species richness, and decreases the production fluxes of phytoliths and PhytOC by reducing aboveground biomass. Grassland restoration can theoretically enhance the production fluxes of phytoliths and PhytOC ~ five-fold.

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1. Introduction

Grasslands account for >20% of global terrestrial area, and they play a crucial role in livestock farming and global carbon (C) cycles (Blecker et al., 2006; Jiang et al., 2006; Song et al., 2012). Due to climate drying and human activities (e.g., overgrazing, cropland misuse, excessive exploitation of fuel, and unregulated collection of medical plants), half of the world's grassland area has been degraded (Zhao and Zhao, 1993; Zhu and Chen, 1994; Jiang et al., 2006). Desertification, one of the most severe types of grassland degradation, is mainly characterized by aeolian (wind-driven) soil erosion of sandy grasslands in arid and semi-arid regions (Wang, 2000; Yang et al., 2005; Jiang et al., 2006). In China, there are >6.64×10^6 ha lands subjected to desertification in arid, semi-arid and dry sub-humid regions, accounting for ~7% of the territory (Zhang et al., 2016). Such a large-scale desertification not only seriously exacerbates the degradation of the already poor environmental quality, but also increases the problem of poverty in parts of north China (Jiang et al., 2006).

Silicon (Si), the second most-abundant element in the earth's crust, can protect plants from various abiotic and biotic stresses, after uptake by the plant roots in the form of dissolved monosilicic acid (Epstein, 1994; Ma and Yamaji, 2006). Phytoliths are the main deposits of silica (SiO_2) in many plant tissues, especially at the endpoints of transpiration, though the mechanism of SiO_2 deposition is still unclear (Hodson et al., 2005; Schaller et al., 2013). In general, the phytolith content ranges from <0.5% in most dicotyledons to ~ 3% in typical dryland grasses, and may even reach up to 10–15% in the Cyperaceae and in wetland species of the Poaceae (Epstein, 1994; Parr et al., 2010). During the formation of phytoliths in plant tissues, 0.1%–6% organic C, originating largely from photosynthesis, can be incorporated (Parr et al., 2010; Parr and Sullivan, 2011; Zuo and Lü, 2011; Li et al., 2013; Zuo et al., 2017), referred to as C occlusion within phytoliths (PhytOC). Since phytoliths are resistant to decomposition, high temperature and oxidation, the PhytOC can occupy 82% of the total organic C in some soils that are >1000-years old (Parr and Sullivan, 2005). Thus, PhytOC has been considered to be one of the most promising mechanisms of terrestrial biogeochemical C sequestration at a centennial-millennial scale (Parr and Sullivan, 2005; Zuo et al., 2014; Song et al., 2012, 2013; Das et al., 2016), although the significance of PhytOC for global C sequestration has been recently challenged due to the lower C content in phytoliths extracted by rapid H_2SO_4/H_2O_2 digestion (Santos and Alexandre, 2017).

For grassland ecosystems, while phytoliths and PhytOC have been well studied, (Blecker et al., 2006; Song et al., 2012; Qi et al., 2017; Pan et al., 2017), changes in phytolith and PhytOC contents, and in the production fluxes of these plant components in sandy grasslands, as well as their relations to grassland desertification gradients, are not well known, especially in the arid and semi-arid grassland areas of China. Therefore, the aims of this study were to determine the contents of phytoliths and PhytOC in sandy grassland of eastern Inner Mongolia; to assess the phytolith C sequestration potential of sandy grasslands, and to explore the effects of desertification on grassland phytolith C sequestration. This study could enhance our knowledge of changes in phytolith C sequestration resulting from change in grasslands; present some suggestions on how to increase phytolith C sequestration; and contribute to studies of the coupled biogeochemical cycles of C and Si.

2. Materials and methods

2.1. Experimental site and field investigation

This study was conducted in the western part of the Northeast China Transect, Xilingol League, Inner Mongolia, China (Fig. 1). The area lies at 42–44°N and 115–118°E, with an elevation of 840–1496 m. The Northeast China Transect has been used to study the responses of terrestrial ecosystems to global climate change (Zhou et al., 2002). The western area of the Northeast China Transect is mainly comprised of meadow and desert steppes, dominated by a temperate continental climate. The mean annual temperature and precipitation in this area are 0–3 °C and 295 mm, respectively. Grasslands with sandy soil substrates are extensively distributed throughout this region.

We carried out field investigation and sampling in July and August of 2014, when plant growth is at its most mature stage. According to our field investigation, the study area has suffered from different degrees of desertification. One of the obvious desertification features is the regional variation of vegetation coverage. However, it is possible for somewhere without desertification that the vegetation coverage may be sparse. Therefore, we firstly systematically set up 39 sites based on

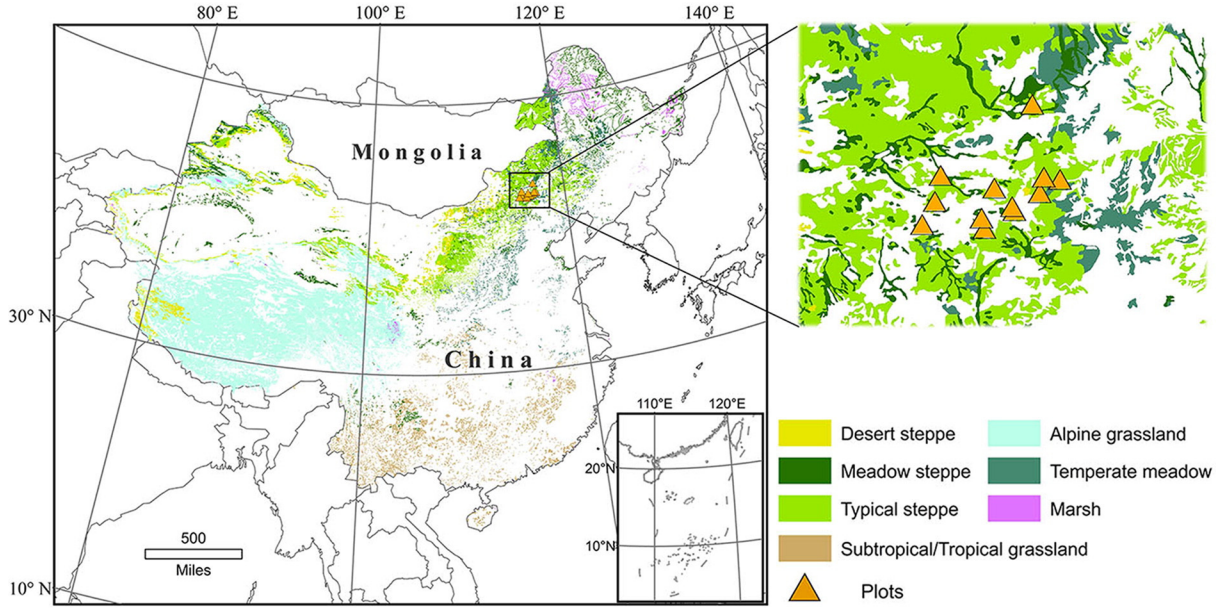

Fig. 1. Distribution of main grassland types in China. Filled triangles indicate sampling sites from eastern Inner Mongolia. The data set is provided by Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC, http://www.resdc.cn).

the variation of vegetation coverage, in order to select sites suffering from desertification. At each site, we randomly set up three replicate 1 m × 1 m quadrats. The coverage, abundance, and height of each plant species were recorded in each quadrat (Table S1). After comprehensively analyzing the vegetation type, species composition and vegetation coverage of different sites, 12 sites of the 39 sites were selected to represent the desertification sites (Table 1). In the field study, the aboveground biomass of each quadrat was harvested to estimate the aboveground net primary productivity (ANPP) (Table 1). Meanwhile, the above-ground parts (approximately 150 g) of the representative species in each quadrat were harvested to assess the contents and production fluxes of both phytoliths and PhytOC, using the method of the community-weighted mean.

2.2. Sample analysis

The samples of aboveground biomass and of the representative species were rinsed with tap water to remove attached dust, rinsed three times with ultrapure water, and dried at 65 °C for 48 h to a constant weight. The dried aboveground biomass samples were directly weighed and the representative species samples were divided into two parts: one part was powdered to analyze the Si content, and the other part was cut to <2 mm to analyze phytolith content. The powdered vegetation samples were fused with Li-metaborate and then dissolved in dilute nitric acid (Li et al., 2013). The Si content of the solution was analyzed by the molybdenum blue colorimetric method, using ultraviolet–visible spectrophotometer (Ji et al., 2017). In order to more reliably quantify the total content of PhytOC, phytoliths were extracted by the modified microwave digestion method; purity of the phytoliths was tested by Walkley-Black type digestion (Walkley and Black, 1934; Li et al., 2013; Parr and Sullivan, 2014). The extracted phytoliths were dried at 65 °C for 24 h in centrifuge tubes, cooled, and then weighed. After the weighed phytoliths were dissolved in 1 mol L^{-1} hydrofluoric acid (HF) solution at 50 °C for 1 h to release C from the phytoliths, the PhytOC concentration of the solution was measured by the traditional potassium dichromate method (Li et al., 2013). The organic C data was monitored with standard soil samples of GBW07405. The precision is better than 7%.

2.3. Data calculations

Importance value (IV) uses plant species height, cover, and abundance to weight each species when constructing a comprehensive index of plant communities (Liu et al., 2008). In each quadrat, the IV of each species was calculated by:

$$IV = (RH + RC + RA)/3 \quad (1)$$

in which RH refers to the relative height, RC refers to the relative cover, and RA refers to the relative abundance of the particular species.

Community-weighted mean (CWM) is broadly used to calculate the community functional traits by many researchers (Ricotta and Moretti, 2011; Qiu et al., 2016). To assess the contents of a measured index (e.g., SiO_2, phytolith, and PhytOC contents) in each plot more comprehensively, we modified the community-weighted mean as follows:

$$CWM\_X = \frac{\sum_{i=1}^{s} IV_i \times X_i}{IV_{ts}} \quad (2)$$

in which X is the measured functional index, CWM_X is the community-weighted mean content of X in each site, IV_i is the importance value of sampled species *i* and can be calculated from formula (1), X_i is the content of X in sampled species *i*, S is the total number of sampled species, and IV_{ts} is the total IV of all sampled species.

In each plot, the production fluxes (PF) of different measured functional indices in the aboveground vegetation could be estimated using the following equation (Song et al., 2012, 2013):

$$PF\_X = ANPP \times CWM\_X \quad (3)$$

in which PF_X is the production flux of the measured functional index (X), ANPP is the aboveground net primary productivity of each site (Table 1), and CWM_X is calculated from formula (2).

2.4. Data statistics

Excel (2010) and SPSS (18.0) were used to statistically analyze the data. One-way analysis of variance (ANOVA) and the least significant difference (LSD) test were applied to examine the differences between the data groups. Figures were made with Origin (8.0).

3. Results

3.1. Variation in the measured indices in sampled species

SiO_2 content of all sampled species varied from 0.94 to 7.88%, and the phytolith content ranged from 0.68 to 9.23% (Table S2). *Calamagrostis epigeios* growing in site 2 had the highest ability to occlude C (2.33%) during the phytolith formation (Table S2). The lowest PhytOC content (0.03‰) was found in *Salsola collina* and *Potentilla longifolia*, growing in sites 1 and 8, respectively (Table S2). In the aboveground part of different species, there was a significant positive correlation ($R^2 = 0.847$, $P < .01$) between SiO_2 content and phytolith content (Fig. 2a). However, there was no significant correlation between the phytolith content and C content of phytoliths (Fig. 2b). A significant positive correlation ($R^2 = 0.558$, $P < .01$) also existed between phytolith content and PhytOC content in the aboveground part of all samples (Fig. 2c).

Table 1
Information of sampling sites.

Sites[a]	Altitude (m)	Vegetation coverage (%)	ANPP (t ha^{-1} $year^{-1}$)	Representative plant species
1	1496	80	1.33	*Psammochloa villosa*, *Salsola collina*, *Artemisia desertorum*, *Leymus chinensis*
2	1335	75	1.32	*Agropyron desertorum*, *Calamagrostis epigeios*, *Scutellaria scordifolia*, *Artemisia frigida*
3	1350	75	1.84	*Bromus ircutensis*, *Potentilla longifolia*, *Leymus chinensis*
4	1357	70	1.46	*Artemisia desertorum*, *Potentilla acaulis*
5	1275	65	1.62	*Psammochloa villosa*, *Carpesium abrotanoides*, *Cleistogenes squarrosa*
6	1360	65	2.08	*Agropyron desertorum*, *Silene jenisseensis*, *Calamagrostis epigeios*, *Bassia dasyphylla*
7	1400	60	1.38	*Agropyron desertorum*, *Calamagrostis epigeios*, *Bromus ircutensis*, *Thymus mongolicus*
8	1350	60	1.04	*Agropyron desertorum*, *Carpesium abrotanoides*, *Potentilla longifolia*
9	1345	50	0.66	*Agropyron desertorum*, *Potentilla nivea*, *Artemisia desertorum*
10	1350	40	0.68	*Artemisia desertorum*
11	1354	35	0.63	*Potentilla longifolia*, *Chamaerhodos erecta*
12	1238	15	0.50	*Psammochloa villosa*, *Chenopodium acuminatum*, *Thymus mongolicus*

[a] Sequence of the sampling sites based on vegetation coverage (high to low).

3.2. Community weighted mean of measured index in different sites

According to community-weighted means of different sampled species, the correlations between SiO_2 content and phytolith content, between phytolith content and C content in the phytoliths, and between phytolith content and PhytOC content in total aboveground biomass of all sampling sites (Fig. S1) were similar to those correlations in each individual plant species (Fig. 2). The content of SiO_2, phytoliths, C in phytoliths, and PhytOC in all sites ranged from 1.30% to 3.65%, from 1.13% to 3.61%, from 0.57% to 1.55%, and from 0.093‰ to 0.349‰, respectively (Table 2). The highest contents of SiO_2 and phytoliths (1.30% and 1.13%, respectively) were found in site 2, while the highest C in phytoliths (1.55%) and the highest PhytOC content (0.349‰) were found in site 7. The average values for the content of SiO_2, phytoliths, C in phytolith, and PhytOC of all species were significantly positively correlated with their community-weighted means (Fig. 3). Furthermore, the phytolith production flux in all sites ranged from 8.94 to 47.8 kg ha^{-1} $year^{-1}$, and the PhytOC production flux ranged from 0.062 to 0.482 kg ha^{-1} $year^{-1}$ (Table 2).

4. Discussion

4.1. Factors of controlling phytoliths and PhytOC contents in sandy grasslands

Grassland represents a particularly large and active biogenic Si pool in terrestrial ecosystems (Blecker et al., 2006; Song et al., 2012; Haynes, 2017). The constructive species of undisturbed grassland (e.g., members of the *Poaceae* and *Cyperaceae*) can generally accumulate Si to concentrations of 1–3%, though some accompanying species (e.g., members of the *Fabaceae*) are Si excluders (Epstein, 1994; Conley, 2002; Schaller et al., 2016; Table 2). Many monocots are considered to accumulate more Si than non-monocot plant species (Epstein, 1994). However, a high Si content is not a general feature of monocots (Hodson et al., 2005). For example, many indicator species of degraded grassland (e.g. *Artemisia desertorum*) also accumulate a large amount of Si during their growth (Table S2). As phytoliths are the main deposits of Si in plant tissues, phytolith content is significantly positively correlated with SiO_2 content (Fig. 2a). This finding is supported by the studies of Parr et al. (2010), Song et al. (2012, 2013), Huang et al. (2015) and Yang et al. (2016).

In sandy grasslands, the phytolith content in plants ranges from 0.68% to 9.23% (Table 2). Hodson et al. (2005) and Yang et al. (2015) studied the effects of phylogenetic variations on the Si content of plants, suggesting that Si content, and thus phytolith production, was more likely influenced by the higher-level phylogenetic position of a plant species. In present study, the phytolith contents of the some plant species growing in different sampling sites are markedly different (Table S2). For example, the phytolith content of *Artemisia desertorum* growing in site 1, 4, 9 and 10 is 1.23%, 0.68%, 3.46% and 1.88%, respectively (Table S2). As the sampling sites are systematically selected based on the variation of vegetation coverage, the environmental conditions among some of these sites are different (e.g., the desertification status of site 9 and site 10 is more serious than that of site 1 and site 2). In addition, compared with previous studies, the phytolith content of *Leymus chinensis* growing in site 1 (1.89%; Table S2) is lower than that growing in meadow steppes (2.44%; Song et al., 2012) and temperate forests (2.53%; Yang et al., 2015). These differences are probably caused by environmental factors such as the weathering stage of the underlying rocks, latitude, temperature, topography, land-use change, and the availability of water and Si in different soil types (Henriet et al., 2008; Parr et al., 2010; Parr and Sullivan, 2011; Zhang et al., 2012; Yang et al., 2016; Ying et al., 2016).

During the formation of phytoliths in sandy grasslands, the present study indicates that 0.37–2.33% C could be occluded (Table S2). Although the content of C occluded by phytoliths is not correlated with the quantity of the phytoliths (Fig. 2b), the percentage of PhytOC on a dry weight basis in sampled plants shows a significantly positive correlation with the phytolith content (Fig. 2c). This is mainly attributed to the phenomenon that plants producing lots of phytoliths are more likely to have more PhytOC in biomass because of the sheer numbers of phytoliths in that biomass, even if the plants do not encapsulate nearly as much PhytOC per phytolith. The study of Parr et al. (2010) suggested that it was the nature of silica deposition and the efficiency of encapsulating C by silica within the cell walls of phytoliths rather than the quantity of phytoliths that determined the relative PhytOC yield (Parr et al., 2010). However, it only focused on bamboo species which all produce large quantities of phytoliths. On the contrary, present study included many plant taxa with a wide range of phytolith production. Therefore, our results imply that the PhytOC content of biomass is more likely controlled by phytolith quantity in sandy grasslands, though the mechanisms underlying the encapsulation of C by silica during the plant growth and its efficiency are still unknown.

4.2. Assessing measures of phytolith and PhytOC production in sandy grassland ecosystems

The composition of communities plays a crucial role when assessing community functional traits, especially for grassland ecosystems (Ricotta and Moretti, 2011; Qiu et al., 2016). For estimating the production fluxes of phytoliths and PhytOC in grassland ecosystems, the importance of species weighting is often overlooked (Song et al., 2012; Qi et al., 2017). After community weighting, there was a significantly positive correlation between community weighted means and the average values of all measured indices in different sampling sites, but the average values were generally higher than the weighted means, except for the content of C in phytoliths (Fig. 3). Thus, using the average values to

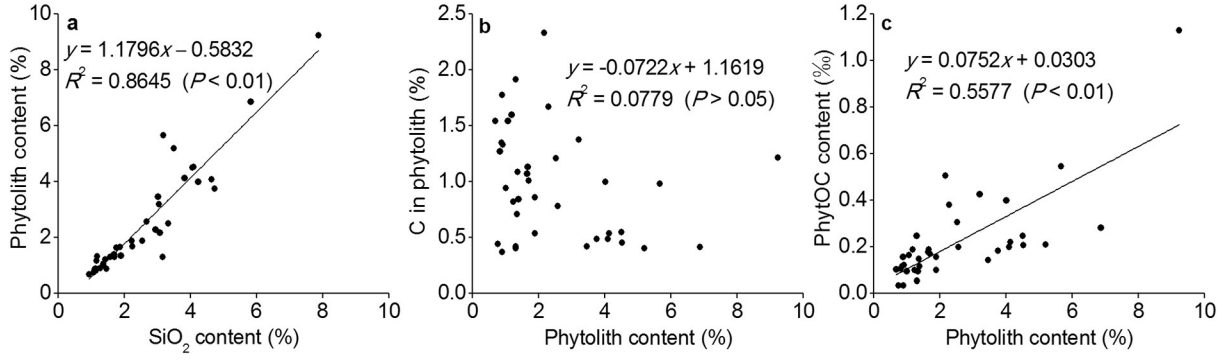

Fig. 2. Relationship (a) between SiO_2 content and phytolith content, (b) between phytolith content and C content in phytoliths, and (c) between phytolith content and PhytOC content in different species.

Table 2
Contents of SiO_2, phytoliths, C in phytoliths and PhytOC, and the production fluxes of phytolith and PhytOC in different sampling sites.

Sites	SiO_2 (%)	Phytoliths (%)	C in phytoliths (%)	PhytOC (‰)	Phytolith production flux (kg ha^{-1} $year^{-1}$)	PhytOC production flux (kg ha^{-1} $year^{-1}$)
1	1.60 (0.06)	1.25 (0.05)	0.79 (0.06)	0.093 (0.004)	16.6 (0.73)	0.123 (0.005)
2	3.65 (0.07)	3.61 (0.14)	1.16 (0.05)	0.324 (0.022)	47.8 (1.91)	0.430 (0.029)
3	1.30 (0.04)	1.13 (0.03)	1.43 (0.03)	0.159 (0.000)	20.8 (0.50)	0.293 (0.000)
4	2.38 (0.13)	2.44 (0.04)	1.09 (0.10)	0.170 (0.013)	35.6 (0.64)	0.249 (0.018)
5	1.57 (0.04)	1.19 (0.01)	1.16 (0.13)	0.134 (0.016)	19.4 (0.08)	0.217 (0.025)
6	1.79 (0.03)	1.47 (0.11)	1.26 (0.03)	0.144 (0.011)	30.6 (2.20)	0.300 (0.022)
7	3.24 (0.07)	2.35 (0.13)	1.55 (0.13)	0.349 (0.033)	32.5 (1.81)	0.482 (0.045)
8	1.79 (0.02)	1.60 (0.13)	0.80 (0.08)	0.153 (0.008)	16.7 (1.35)	0.159 (0.009)
9	2.34 (0.13)	2.43 (0.09)	0.81 (0.06)	0.155 (0.008)	16.0 (0.58)	0.102 (0.005)
10	2.24 (0.08)	1.88 (0.36)	0.86 (0.16)	0.156 (0.000)	12.8 (2.46)	0.106 (0.000)
11	2.38 (0.04)	2.02 (0.06)	0.57 (0.03)	0.146 (0.007)	12.8 (0.37)	0.093 (0.004)
12	2.15 (0.06)	1.79 (0.07)	0.83 (0.02)	0.123 (0.004)	8.94 (0.34)	0.062 (0.002)

Data present as community-weighted means with standard deviation (in brackets).

assess the contents of SiO_2, phytoliths, and PhytOC in sandy grasslands may overestimate the results. Considering that the correlations between SiO_2 content and phytolith content, between phytolith content and C content in the phytoliths, and between phytolith content and PhytOC content in all sampling sites after weighting (Fig. S1) were similar to those correlations in each individual plant species (Fig. 2), the present study suggested that using the weighted mean to assess the production of SiO_2, phytoliths, and PhytOC in sandy grasslands was more reliable than using the arithmetic mean.

4.3. Effects of desertification on phytolith and PhytOC production

Desertification, one of the most severe types of grassland degradation, mainly occurs in sandy grasslands in arid and semi-arid regions (Wang, 2000; Yang et al., 2005; Jiang et al., 2006). According to our field investigation, all of our sampling sites have suffered from different degrees of desertification. In general, desertification can lead to decreases in plant biodiversity, aboveground biomass, and ANPP of the grasslands (Yang et al., 2005). In the present study, the significant positive correlation between vegetation coverage and ANPP in different sites implies that, the lower the vegetation coverage, the more severe the desertification (Fig. 4a). To assess the effects of desertification process on the distribution and production of phytoliths and PhytOC, all the desertification sites are categorized into three groups, based on the variation range of current vegetation coverage, namely ≥70%, 70–50%, and ≤50%, respectively (Fig. 5). Although these three groups do not represent the actual degree of desertification, they can imply the increasing trend of desertification to some extent.

It is reported that the storage of soil nutrients decreases significantly as grassland desertification progresses (Larney et al., 1998; Duan et al.,

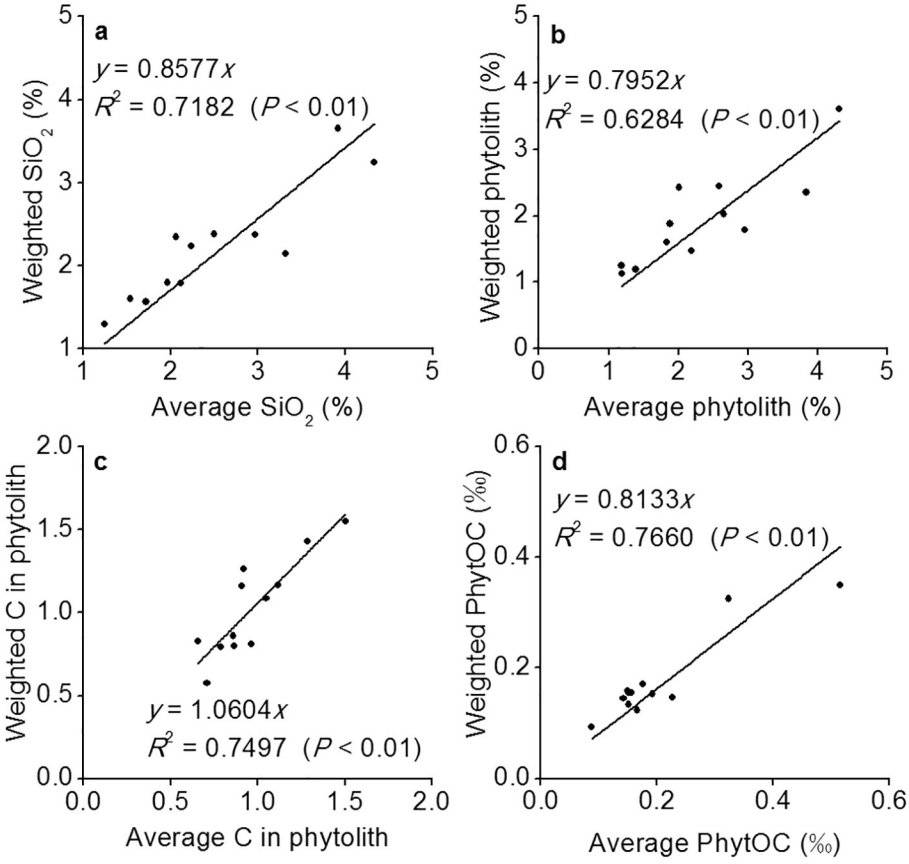

Fig. 3. Relationship between average values and community weighted means of measured indices for all sampled species in different sampling sites. (a) SiO_2, (b) phytolith, (c) C in phytolith, and (d) PhytOC.

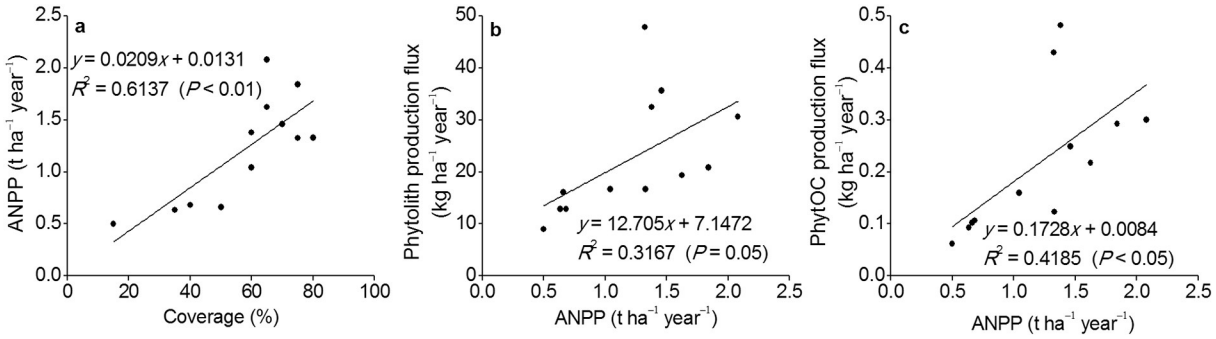
a
y = 0.0209x + 0.0131
R² = 0.6137 (P < 0.01)
ANPP (t ha⁻¹ year⁻¹)
Coverage (%)
b
y = 12.705x + 7.1472
R² = 0.3167 (P = 0.05)
Phytolith production flux (kg ha⁻¹ year⁻¹)
ANPP (t ha⁻¹ year⁻¹)
c
y = 0.1728x + 0.0084
R² = 0.4185 (P < 0.05)
PhytOC production flux (kg ha⁻¹ year⁻¹)
ANPP (t ha⁻¹ year⁻¹)

Fig. 4. Relationship (a) between vegetation coverage and ANPP, (b) between ANPP and phytolith production flux, and (c) between ANPP and PhytOC production flux in different sampling sites.

2001; Feng et al., 2002; Zhou et al., 2008; Kukal and Bawa, 2014). However, the contents of phytoliths and PhytOC in aboveground vegetation exhibit no significant variation among sites of different desertification status (Fig. 5a, b). Zhou et al. (2008) has confirmed that, as well as phytolith and PhytOC contents, the concentration of C and nitrogen in plants and plant litter do not significantly decrease with the desertification process. These findings indicate that the effects of desertification process on the total contents of phytoliths and PhytOC in the aboveground biomass are weak.

In our study areas, as the stage of desertification increased, the complex plant community gradually degenerates into simple community comprised mainly of drought-resistant sandy species (e.g. *Artemisia desertorum*, *Psammochloa villosa*, *Agropyron desertorum*). The decrease in plant biodiversity means that the variation in the range of phytolith and PhytOC contents in aboveground vegetation decreased because the phytolith and PhytOC contents varied among the different plant species (Hodson et al., 2005; Parr et al., 2010; Zuo and Lü, 2011; Yang et al., 2015; Table S2). Correspondingly, the exacerbation of desertification will influence the distribution patterns of phytolith and PhytOC content (Fig. 5a, b). Furthermore, the production fluxes of phytoliths and PhytOC are significantly correlated with the ANPP of aboveground vegetation in terrestrial ecosystems (Blecker et al., 2006; Song et al., 2012; Fig. 4b, c), which results in a decline in both the variation ranges and the values of phytolith production flux, as well as PhytOC production flux, as desertification proceeds on a regional scale (Fig. 5c, d).

Generally, as long as the desertification status has not exceeded the capacity for self-recovery, grasslands generally restore themselves when grazing is stopped (Liu et al., 2002). For example, both the vegetation coverage and species richness in extremely degraded sandy grassland increase over time following exclosure and grazing prohibition in an attempt to achieve natural revegetation (Zhang et al., 2016). In addition, appropriate nitrogen addition to degraded grasslands is also an effective way to enhance the aboveground biomass (Xu et al., 2015) and the phytolith and PhytOC contents in herbs (Zhao et al.,

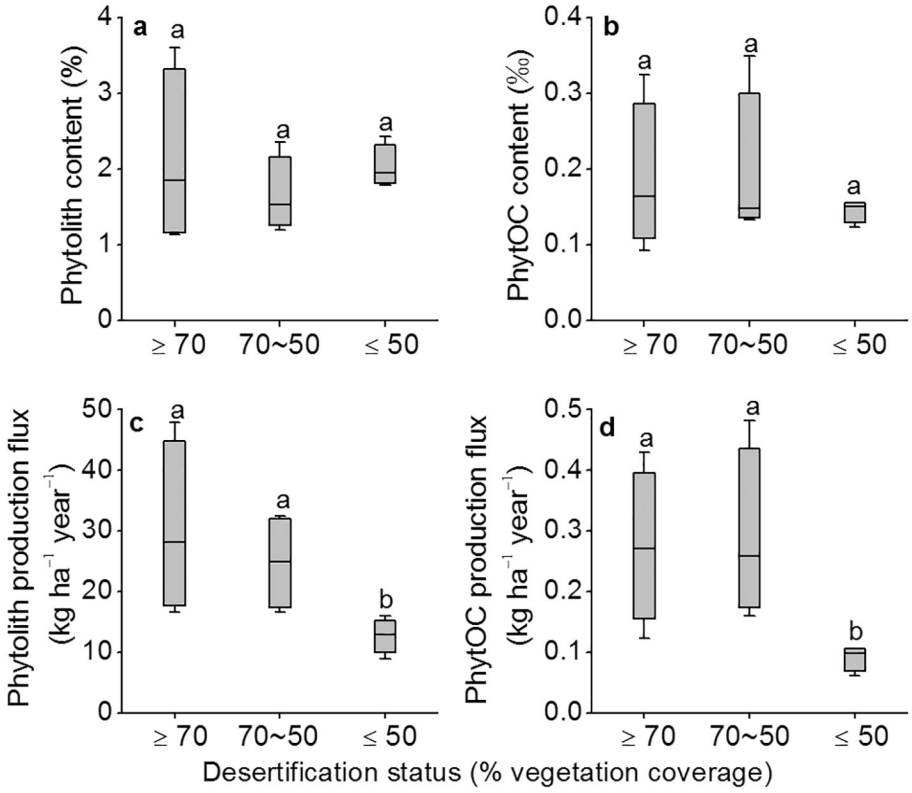

Fig. 5. Boxplots showing variations in (a) phytolith content, (b) PhytOC content, (c) phytolith production flux, and (d) PhytOC production flux under different desertification status. Different lowercase letters indicate significant differences between groups at $P < .05$ level based on the least significant difference (LSD) test. The top, mid and bottom line of the box represent the upper quartiles, median and lower quartiles, respectively. The top and bottom bar represent the maximum and minimum, respectively.

2016). Therefore, if the severe desertification grassland could recover to its initial level, the production fluxes of phytoliths and PhytOC would markedly increase at least five-fold. In present study, only the aboveground vegetation was considered. Further studies in sandy grasslands are required to assess more comprehensively the effects of desertification on phytolith C sequestration, as well as the coupled cycles of C and Si.

5. Conclusions

In sandy grasslands, phytolith and PhytOC contents among different plant species varied from 0.68 to 9.23% and from 0.03 to 1.13‰, respectively. The phytolith and PhytOC contents of the total aboveground vegetation in sandy grasslands were 1.13–3.61% and 0.09–0.35‰, respectively. Production flux of the phytoliths and PhytOC ranged from 8.94 to 47.8 kg ha^{-1} $year^{-1}$ and from 0.06 to 0.48 kg ha^{-1} $year^{-1}$, respectively. Although the grassland desertification status did not significantly affect the phytolith and PhytOC contents of the total aboveground vegetation, the distribution patterns and production fluxes of phytoliths and PhytOC could be markedly influenced as desertification progressed. With the exacerbation of desertification, the variation ranges and values of phytolith and PhytOC production flux decreased. Restoration of grassland could theoretically improve phytolith and PhytOC production flux ~ five-fold. As the stability and storage of phytoliths and PhytOC in sandy grassland soils are still unknown, future follow-up work on this topic should include measurement of phytoliths and PhytOC in these grassland soils.

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